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Short Communication

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Application of Stress Indices for Heat Tolerance Screening of Common Bean

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With 3 tables

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Abstract

Common bean is adapted to relatively cool climatic conditions and temperatures of > 30 °C during the day or > 20 °C at night result in yield reduction. The long-term goal of breeding for heat tolerance is the development of germplasm with improved field level tolerance under variable temperature conditions. Using previously developed stress indices, this study presents results from high temperature screening of 14 genotypes in both the greenhouse and field in Puerto Rico. A total of three sets of paired trials were conducted in the field and in the greenhouse under high temperature (stress) and lower temperature (low-stress) conditions. The geometric mean (GM), stress tolerance index (STI) and stress susceptibility index (SSI) were used to evaluate the genotypic performance under stress and low-stress conditions. The results indicate that it was possible to identify superior genotypes for heat tolerance based on their stress indices. In this evaluation of heat tolerance indices, STI and GM, although correlated, were found to be effective stress indices for the selection of genotypes with good yield potential under stress and low-stress conditions.

Key words: *Phaseolus vulgaris* — stress index — temperature response

Introduction

Common bean (*Phaseolus vulgaris* L.) is adapted to relatively cool climatic conditions with optimal average daily temperature for reproductive development ranging from 20 to 25 °C (Wantanbe 1953). Temperatures of > 30 °C during the day or > 20 °C at night result in yield reduction (Rainey and Griffiths 2005). The physiological response of common bean to high temperature stress has primarily been studied through the use of controlled environmental testing in the greenhouse and growth chamber. However, the long-term goal of breeding for heat tolerance is the development of germplasm with improved field tolerance under variable temperature conditions. Thus, yield stability under variable high day and night temperature conditions is sought as well as competitive yield under low-stress conditions.

Although studies have begun to elucidate the genetics and physiology of the reaction to high temperature stress in common bean, yield-based indices are needed for the evaluation of high temperature tolerance for applied plant breeding programmes. Few heat stress indices have been developed for the evaluation of high ambient temperature stress in plants. One index, the thermal stress index in cotton (Burke et al. 1990), is based only on foliar temperatures. Several yield-based stress indices have been developed that may be more applicable to work on heat tolerance. The geometric mean (GM) and the stress tolerance index (STI) (Fernandez 1993) have been used for comparing genotypic performance across years or environments. STI was developed to identify genotypes that perform well under both stress and non-stress conditions. The stress susceptibility index (SSI) (Fisher and Maurer 1978) is a ratio of genotypic performance under stress and non-stress conditions, adjusted for the intensity of each trial, and has been found to be correlated with yield and canopy temperature in wheat (Rashid et al. 1999). In addition, deviations from the regression of stressed on non-stressed yield have been used to identify lines with stress tolerance in bean (Beebe et al. 1997, Smith 2004). The GM and the susceptibility index have been used widely for the determination of genotypic differences under drought stress in common bean (refer to Ramirez-Vallejo and Kelly 1998). These different indices may be applicable to other abiotic stress traits, such as high temperature tolerance. This study presents results from high temperature screening of bean germplasm under greenhouse and field conditions in Puerto Rico using indices to select stress-tolerant lines with good yield potential.

Materials and Methods

Most of the genotypes assembled for testing in this study have shown some level of heat tolerance. Amadeus, EAP 9503-32A, EAP 9503-32B, SRC 1-12-1-182, SRC 1-12-1-48, and Tio Canela are small red Mesoamerican varieties (named) and lines (numbered) developed at the Escuela Agricola Panamericana, Zamorano, Honduras by Dr Juan C. Rosas. Lines 98020-3-1-7-2 and 98012-3-1-2-1 were developed at the USDA-ARS in Mayaguez, Puerto Rico for tolerance to root rot and common bacterial blight under high temperature conditions (Dr R. Smith, personal communication). VAX 6, DOR 557 and Morales are small seeded beans from the Mesoamerican gene pool. IJR, G 122 and Montcalm are large seeded, Andean beans; IJR (Baiges et al. 1996, Román-Avilés and Beaver 2003) and G122 (Porch and Jahn 2001) have shown moderate heat tolerance.

Paired trials, one under high ambient temperature and one under lower temperature, were conducted in the field and greenhouse. Due to the inability to test two ambient temperature regimes in one field environment, low-stress and stress locations with different planting dates were used to compare yield performance. The field experiments conducted under low-stress (F05-L) conditions in Isabela, Puerto Rico were planted on 29 March 2005; and under high temperature conditions (F05-H) in Juana Diaz, Puerto Rico on 28 June 2005 (Table 1). Field trials were planted in a completely randomized block design with 12–15 plants per replication and three replications per location. Single row plots were planted of 1-m length and 0.9 m between rows. Trials were watered as needed, using drip irrigation, in order to avoid drought stress. Ten plants were selected from the centre of the plots for the determination of yield. One genotype, DOR 557, was not tested in the field environment (Table 1).

Two paired trials were conducted in the greenhouse. One pair of trials was planted on 24 August 2004 (G04-L and G04-H) and the second on 25 August 2005 (G05-L and G05-H). In the greenhouse trials, plants were grown individually in 15-cm-round pots in Sunshine Mix no. 1 (Sun Gro Horticulture, Vancouver, BC, Canada), watered regularly to avoid drought stress, treated with pesticides as needed, and fertilized with Osmocote (14-14-14; N-P-K, Marysville, OH, USA). All plants were first grown in the low-stress greenhouse and then one-half were transferred to a high temperature greenhouse at approximately 3 days before the start of anthesis. Each experiment was conducted using a randomized complete block design with four replicates and one plant per replication. One genotype, Amadeus, was not tested in the G04 greenhouse trial.

The statistical analyses were conducted using Statistix (Analytical Software, Tallahassee, FL, USA) and Minitab (Minitab Inc., State College, PA, USA) software on seed yield per plot in the field trials and seed yield per plant in the greenhouse trials. Temperature and humidity data were collected on Hobo Pro dataloggers (Onset Computer Company, Pocassett, ME, USA) at intervals of 1 min in greenhouse and field trials, with the exception of FO5-L (Table 1) where on-farm weather station data was used instead. Maximum, minimum, and average temperatures and relative humidity were then determined for each day of the trial during the period of reproductive development (approximately 6 weeks; Table 1). The heat susceptibility index (HSI; $(1 - (Y_s/Y_p))/(1 - (X_s/X_p))$), GM ($(Y_s \times Y_p)^{1/2}$), heat tolerance index (HTI; $(Y_p \times Y_s)/X_{p^2}$), and heat intensity index (HII; $1 - (X_s/X_p)$ were determined using the equations for SSI (Fisher and Maurer 1978), GM, STI and SI (Fernandez 1993) respectively. The high temperature yield data and lower temperature yield data from the paired trials in this study were used in place of the genotypic mean values for yield under stress (Y_s) and potential yield under

Table 1: Temperature and humidity of paired field and greenhouse trials in Puerto Rico for evaluation of the high temperature stress response in common bean[1]

		Temperature (°C)			Relative humidity (%)		
Trial[2]	Location	Average	Maximum	Minimum	Average	Maximum	Minimum
F05-L	Isabela	25.2 (0.9)	28.8 (1.3)	22.0 (1.3)	82.5 (4.7)	92.3 (2.9)	65.6 (7.3)
F05-H	Fortuna	27.4 (0.9)	33.4 (1.1)	23.4 (1.0)	82.9 (4.4)	96.5 (1.7)	58.6 (6.1)
G05-L	Mayaguez	26.9 (1.0)	34.1 (2.4)	22.9 (0.7)	86.8 (4.0)	98.8 (1.2)	57.6 (10.1)
G05-H	Mayaguez	28.5 (1.2)	37.1 (2.6)	23.8 (0.8)	85.6 (3.9)	96.2 (1.6)	59.2 (9.4)
G04-L	Mayaguez	27.1 (1.2)	35.8 (1.9)	22.1 (1.8)	81.2 (4.6)	96.7 (1.5)	47.0 (7.1)
G04-H	Mayaguez	29.2 (1.5)	41.5 (2.5)	22.9 (0.7)	77.6 (5.9)	93.8 (2.6)	40.8 (8.4)

Standard deviation values are in parentheses.

[1]Greenhouse trials planted concurrently; field trials planted during different seasons at different locations.

[2]F, field; G, greenhouse; H, high temperature trial; L, low temperature trial; planted in 2004 (04) and 2005 (05).

non-stress (Y_p) variables, respectively, in the equations for the above indices. X_s and X_p are the mean yield of all genotypes per trial under stress and non-stress conditions.

Results and Discussion

The results indicate that several of the genotypes were superior for heat tolerance based on the stress indices and on the consistency of their reactions across environments. Specifically, SRC-1-12-1-182, SRC-1-12-1-48, 98020-3-1-7-2, and 98012-3-1-2-1 showed high HTI and GM and relatively low HSI values (Table 2). These genotypes showed relatively consistent high temperature tolerance across the field and greenhouse trials. Because there were two pairs of greenhouse trials and one pair of field trials in this study, the rankings, which were based on averages of HTI across trials, are skewed towards performance in the greenhouse. Because Amadeus and DOR 557 were not tested across all environments, it is difficult to compare their reactions to the other genotypes in terms of average scores; however, it is likely that Amadeus was over-rated because it was not tested in the most severe trial (G04) and that DOR 557 was under-rated because it was not tested in the least severe trial (F05). Both Amadeus and DOR 557 appear to be good performers under heat stress. Based on GM and HSI, IJR was also a good performer, however, it showed limited yield potential under field conditions. Lower yield potential of several Andean genotypes (G122 and Montcalm) could be due to plant habit, which may have contributed to the Andean genotypes having lower (and thus better) HSI scores. Due to the determinate flowering phenology of type I Andean genotypes, characterized by a short and abundant flush of flowers at the initiation of reproductive development, they likely have an advantage under the greenhouse high temperature environment where the plants are only subjected to high temperature conditions beginning at the onset of flowering. More flowers in a determinate genotype, as compared to an indeterminate genotype, would thus be exposed to a shorter period of high temperature stress (Table 2).

Two general screening environments were chosen in Puerto Rico, greenhouse and field. The paired

Table 2: Analysis of the geometric mean (GM), heat susceptibility index (HSI) and heat tolerance index (HTI) on seed yield for three trials under high temperature stress conditions[1]

	Seed yield/plant (greenhouse) or seed yield/plot (field) (g)												Average across trials	
	Field 2005				Greenhouse 2004				Greenhouse 2005					
Genotype	GM	HSI	HTI	Rank[2]	GM	HSI	HTI	Rank	GM	HSI	HTI	Rank	HSI	HTI
SRC1-12-1-182	116.7	0.83	0.82	3	1.07	1.01	0.02	2	7.02	0.48	0.88	1	0.77	0.57
Amadeus	95.7	1.17	0.55	5	NT	NT	NT	NT	4.86	1.09	0.42	3	1.13	0.49
SRC1-12-1-48	117.4	0.59	0.83	2	0.24	1.02	0.00	8	4.51	0.98	0.36	5	0.86	0.40
98020-3-1-7-2	110.4	0.83	0.74	4	0.56	0.99	0.01	7	4.80	1.05	0.41	4	0.96	0.38
98012-3-1-2-1	119.2	0.76	0.86	1	0.00	1.02	0.00	9	3.26	1.14	0.19	8	0.97	0.35
IJR	46.1	0.72	0.13	11	3.15	0.94	0.21	1	4.36	0.71	0.34	6	0.79	0.23
G 122	13.0	1.45	0.01	13	0.79	0.80	0.01	5	5.14	0.75	0.47	2	1.00	0.16
EAP 9503-32A	68.8	1.04	0.29	6	0.88	0.92	0.02	4	1.46	1.21	0.04	12	1.06	0.11
DOR 557	NT[3]	NT	NT	NT	1.05	1.01	0.02	3	3.40	1.10	0.21	7	1.06	0.11
VAX 6	61.3	1.25	0.23	9	0.00	1.02	0.00	10	2.21	1.12	0.09	10	1.13	0.10
Tio Canela	63.0	0.99	0.24	7	0.00	1.02	0.00	11	0.80	1.25	0.01	14	1.09	0.08
EAP 9503-32B	62.0	1.17	0.23	8	0.00	1.02	0.00	12	0.90	1.25	0.01	13	1.15	0.08
Morales	49.7	1.26	0.15	10	0.00	1.02	0.00	13	2.40	1.15	0.10	9	1.15	0.08
Montcalm	28.7	1.14	0.05	12	0.73	0.99	0.01	6	1.85	1.01	0.06	11	1.05	0.04
X_p, X_s	128.5, 44.3				6.8, 0.2				7.5, 1.7					
HII[4]	0.66				0.98				0.77					

[1] $GM = (Y_s \times Y_p)^{1/2}$; $HSI = (1 - (Y_s/Y_p))/(1 - (X_s/X_p))$; $HTI = (Y_p \times Y_s)/X_p^2$, where Y_s and Y_p indicate genotypic yield under stress and non-stress conditions (respectively), and X_s and X_p are the mean yield of all genotypes per trial under stress and non-stress conditions respectively.
[2] Ranked by HTI.
[3] NT, not tested.
[4] Heat intensity index (HII) $= 1 - (X_s/X_p)$.

Table 3: Correlation analysis between yield and stress indices for three trials[1]

Correlation	Trial[2] G04	G05	F05
H × L	0.06	0.48	0.69
H × H/L	0.60	0.96	0.84
H × GM	0.94	0.93	0.96
H × HSI	−0.60	−0.96	−0.84
H × HTI	0.92	0.97	0.97
L × H/L	−0.49	0.25	0.28
L × GM	0.20	0.75	0.86
L × HSI	0.49	−0.25	−0.28
L × HTI	0.34	0.64	0.80
H/L × GM	0.41	0.82	0.70
H/L × HSI	−1.00	−1.00	−1.00
H/L × HTI	0.26	0.86	0.70
GM × HSI	−0.41	−0.82	−0.70
GM × HTI	0.93	0.97	0.98
HSI × HTI	−0.26	−0.86	−0.70

[1]Field yield is average seed yield/plot; Greenhouse yield is average seed yield/plant.
[2]G04, Greenhouse 2004; G05, Greenhouse 2005; F05, Field 2005; H, high temperature yield; L, lower temperature yield; GM, geometric mean; HSI, heat susceptibility index; HTI, heat tolerance index.

trials varied in terms of their HII (Table 2). The field (F05) trial was the least severe (HII = 0.66) and the 2004 greenhouse trial (G04) was the most severe (HII = 0.98) and resulted in the most significant reduction in yield. Due to the high HII of the G04 trial, this trial was less informative and showed the lowest correlation between low and high temperature trials (Table 3), but may be useful for evaluation of lines with high levels of heat tolerance. In general, a more moderate HII should be sought in order to better differentiate genotypes. In terms of average daily temperatures, the higher temperature trials (27.4–29.2 °C) and the lower temperature trials (25.2–27.1 °C) did not overlap. However, the lower temperature trials were still on the upper end of ideal common bean growing temperatures (20–25 °C) and thus probably experienced some temperature stress. Regression analysis of yield (dependent) and temperature or humidity variables (independent) across trials showed that maximum temperature ($R^2 = 0.81$) best explained differences in yield across environments (not shown). Previous work has shown that increases in minimum temperature are most damaging to reproductive development in bean (Gross and Kigel 1994). However, there was little variation across trials for minimum temperature in this study. Although the use of different locations likely added additional confounding factors to the field trials, it was necessary for the application of differential temperature regimes, as different ambient temperatures cannot be applied to a single field site. As was found previously by planting in the winter and summer months (Román-Avilés and Beaver 2003) or by planting in two separate locations and seasons in Puerto Rico, as with this study, it is possible to apply different levels of stress at locations in close proximity. Although the field trial is the most reliable measure of heat tolerance because it is the production environment for common bean, relatively consistent results were achieved between greenhouse and field environments for the top ranking genotypes based on HTI (Table 3).

The heat tolerance index and GM proved to be the most useful indices for the evaluation of genotypic performance under heat stress and they were highly correlated (Table 3), as expected, due to a rank correlation of 1 (Fernandez 1993). A previous study on the common bean in Puerto Rico also found GM to be an effective index (Smith 2004). Deviations from regression were found to be non-significant using an ANOVA with a randomized complete block design, thus the results from this analysis are not presented. HTI, GM and HSI were all correlated with yield under heat stress, whereas HTI and GM were more highly correlated with yield under low-stress conditions than HSI. The correlation of low yield potential and low SSI (HSI) scores have been found in previous work on drought stress in bean (White and Singh 1991), and may make this index less useful in heat tolerance breeding. Despite their correlation, it appears as though both GM and HTI will be useful for breeding for heat tolerance. Depending on how much emphasis is placed on comparisons between sets of trials, the relatively consistent magnitude of HTI makes comparisons between trials more straightforward.

Abiotic stress tolerance is a key component and in some cases the major factor (Tollenaar and Wu 1999) in improving yield in crops. Heat stress is an important constraint and will play an increasing role in common bean yields due to global climate change. In this evaluation of heat stress under field and greenhouse conditions in Puerto Rico, HTI (STI) and GM appear to be the most effective stress indices for the selection of genotypes with good yield potential under stress and low-stress conditions.

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Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture.

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